AD-A101 112 NATIONAL BUREAU OF STANDARDS BOULDER COLO F/G 14/2
COOLED ION FREQUENCY STANDARD (FY81).(U)
1981 D J WINELAND, F L WALLS N00014-81-F-0003
UNCLASSIFIED NL

1 OF 1
AD A101112

END
DATE FILMED
7-81
DTIC

LEVEL

(12)

Summary of Work on

"COOLED ION FREQUENCY STANDARD"

(FY81)

ONR Contract No. N00014-81-F-0003

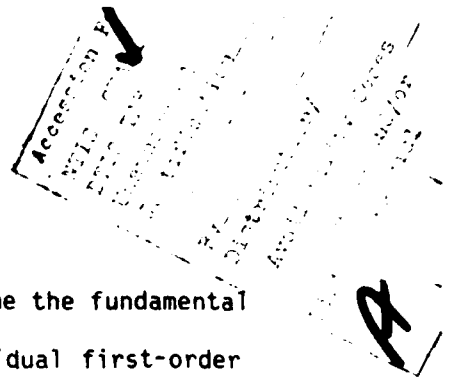
Co-Principal Investigators

D. J. Wineland
Frequency & Time Standards Group
524.04
National Bureau of Standards
Boulder, Colorado 80303

FTS: 320-5286
(303) 497-5286

F. L. Walls
Frequency & Time Standards Group
524.04
National Bureau of Standards
Boulder, Colorado 80303

FTS: 320-3207
(303) 497-3207



Contract Description

The purpose of this work is to develop techniques to overcome the fundamental limits of present frequency standards--the second and residual first-order Doppler shifts. To this end, we study suitable frequency reference transitions in ions which are stored in electromagnetic traps and cooled by radiation pressure to < 1K.

Scientific Problem

Although we have now demonstrated laser cooling to < 0.1K and have identified some of the causes for the present limit, we will try to approach the theoretical limit of 10^{-3}K. To this end, we will continue studies of a single ion in the trap. In addition, we will try to tailor clouds of modest density that are relatively free of magnetron velocity effects. It should also be possible to observe condensation of the ion cloud into a liquid or solid. We will continue to incorporate the cooling into high resolution spectroscopy and use the fluorescence as a monitor in a triple resonance scheme which should allow us to obtain linewidths of less than 0.01 Hz. Such experiments should allow us to study problems generic to all ion frequency standards.

Scientific and Technical Approach

A special apparatus will be completed with improved detection efficiency, so that the fluorescence from a single ion can be more easily observed. This improved detection efficiency will also be beneficial in the double resonance experiments. It is desirable to use a light ion such as Be^+ and higher magnetic

fields, so that at a given temperature, the cyclotron and axial amplitudes are much smaller. A "prototype" microwave frequency standard based on $^{201}Hg^+$ ions in a Penning trap will be developed. This device has a design goal of inaccuracy $\leq 10^{-15}$ and frequency stability $< 10^{-15}$. Dye laser stabilization schemes will be investigated for possible application to optical frequency standards.

Progress During Last Contract Period

A. Mg^+ studies

1. Single ion experiments. Single $^{24}Mg^+$ ions have been isolated in a Penning trap and double resonance experiments performed. Theoretical calculations for laser cooling of single ions are exact; therefore these experiments allow a detailed comparision of theory with experiment. Cyclotron - magnetron "temperatures" of about 0.05 K have been obtained.

2. Precision hyperfine structure (hfs) measurements of $^{25}Mg^+$. Our measurements give the first precision determination of $^{25}Mg^+$ hfs. The techniques used in these measurements for laser cooling, optical pumping, and double resonance detection are nearly the same as the methods that will be used in a prototype stored ion frequency standard. Therefore these measurements have a direct bearing on the frequency standard problem.

3. Observation of ultra narrow linewidths. We have observed linewidths of 0.012 Hz in a particular $^{25}Mg^+$ hfs transition. ($\nu_o \cong 292$ MHz, $Q = 2.4 \times 10^{10}$) These very narrow linewidths are

about two orders of magnitude more narrow than observed by other groups; moreover, the narrow linewidths should be achievable on hfs transitions in other ions at higher frequencies, eg. Hg^+.

B. Theoretical studies

1. Microwave stored ion frequency standards. We have studied the generic problems for stored ion frequency standards by making a detailed proposal for a prototype frequency standard based on $^{201}Hg^+$ ions. These studies indicate that it should be possible to achieve accuracies better than 10^{-15}.
2. Laser cooling in a Penning trap. Our previous theoretical treatments have dealt only with ions bound in harmonic traps. We have addressed the practical case of ions in a Penning trap and will publish these results.

C. New Apparatus

1. A separate laboratory is now being set up for the $^{201}Hg^+$ project. Work has already begun on generating cw, narrowband radiation at 194 nm, which is required for laser cooling and optical pumping in Hg^+.
2. A new appartus for Be^+ has been completed (but not yet tested). The main feature of this apparatus is that fluorescence collection efficiency should be increased by 100 to 1000 over the Mg^+ apparatus. This will allow much easier study of cooling and cloud dynamics.

D. Ion storage publications in preparation or published since May 80.

1. "Double-resonance and optical-pumping experiments on electromagnetically confined, laser cooled ions." D. J. Wineland, J. C. Bergquist, Wayne M. Itano, and R. E. Drullinger, Opt. Lett. 5, 245 (1980).
2. "High-resolution optical spectra of laser cooled ions" R. E. Drullinger, D. J. Wineland, and J. C. Bergquist, Appl. Phys. 22, 365 (1980).
3. "Spectroscopy of a Single Mg^+ Ion" D. J. Wineland, and Wayne M. Itano, Phys. Lett. 82A, 75 (1981).
4. "The Isolated Electron" Philip Ekstrom and David Wineland, Sci. American 243, 105 August 1980.
5. "Future Atomic Frequency Standards" D. J. Wineland, Proc. Seminaire sur Les Etalons de frequence, Laboratoire de Physique et Metrologie des Oscillateurs, Besancon, France March, 1981.
6. "Precision measurement of the ground state hyperfine constant of $^{25}Mg^+$". Wayne M. Itano and D. J. Wineland, Phys. Rev. A, to be published.
7. "Laser cooling of ions stored in harmonic and Penning traps." Wayne M. Itano and D. J. Wineland, submitted to Phys. Rev. A.
8. "Proposed stored $^{201}Hg^+$ ion frequency standards" D. J. Wineland, Wayne M. Itano, J. C. Bergquist and F. L. Walls. Proc. 35th Ann. Symp. Frequency control, Philadelphia, Pa May 1981, to be published.
9. "Spectroscopy of Stored Ions" D. J. Wineland, (review paper) Proc. 2nd Int. Conf. Prec. Meas. Fundamental Constants. Gaithersburg, Md. June 1981 to be published.

10. "Progress toward a Stored Ion Frequency Standard at NBS", Wayne M. Itano, D. J. Wineland, J. C. Bergquist, F. L. Walls. ibid.

E. Awards

Department of commerce silver medal awarded to R. E. Drullinger, F. L. Walls, and D. J. Wineland for the initial work on laser cooling.

F. Invited talks on ion storage since May 80.

1. Washington Univ., St. Louis, D. J. Wineland.
2. Univ. of Colorado, Boulder, Colorado, D. J. Wineland.
3. John Hopkins Univ., Baltimore, MD. D. J. Wineland.
4. N. C. State Univ., Raleigh, N. C., D. J. Wineland.
5. AAPT/APS Winter meeting, N.Y., N.Y. D. J. Wineland.
6. Bell Labs, Holmdel, N.J., D. J. Wineland.
7. I.B.M. Yorktown Heights, N.J., D. J. Wineland.
8. Laboratoire de Physique et Metrologie des Oscillators, Besancon, France, D. J. Wineland.
9. Precision Measurements and Fundamental Constants Conference, Bethesda, Md. D. J. Wineland.
10. Fifth International Conference on Laser Spectroscopy, Jasper, Canada, Wayne M. Itano.
11. Gordon Conf. on Atomic Physics, Wolfeboro, N. H., D. J. Wineland.

Miscellaneous

A. All FY81 funds will be spent by end of contract year.

B. Other contract support of principal investigators:

David J. Wineland and F. L. Walls

AFOSR $100 k "Precision Frequency Metrology Using Laser Cooled Ions."

F. L. Walls and Karl Persson

NRL $40 k Development of Hydrogen Discharge Source capable of operation in vacuum.

F. L. Walls and David A. Howe

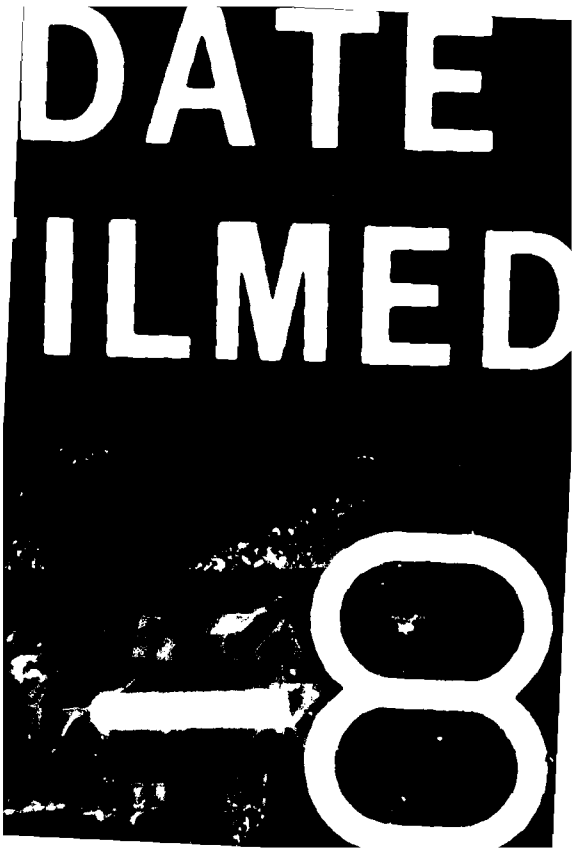
JPL $50 k Development of UH_3 source for hydrogen masers.

F. L. Walls and Lindon Lewis

GPS-JPO $34.5 k Consulting on clocks and clock development.

C. KEY PERSONNEL (FY81)

Co-Principal Investigators	D. J. Wineland	(40%)
	F. L. Walls	(10%)
Senior Staff Scientists	J. C. Bergquist	(25%)
	W. M. Itano	(25%)
Research Associate	H. Hemmati	(40%)
	(6 months)	


DATE
ILMED
8